Electronics II Final Solution   2016/6/3

#1

a.

$$I_1 = \frac{20 - V_{GS3}}{50} = 0.25\left(V_{GS3} - 2\right)^2$$

$$20 - V_{GS3} = 12.5\left(V_{GS3}^2 - 4V_{GS3} + 4\right)$$

$$12.5V_{GS3}^2 - 49V_{GS3} + 30 = 0$$

$$V_{GS3} = \frac{49 \pm \sqrt{(49)^2 - 4(12.5)(30)}}{2(12.5)} \Rightarrow \underline{V_{GS3} = 3.16\text{ V}}$$

$$I_1 = \frac{20 - 3.16}{50} \Rightarrow \underline{I_1 = I_Q = 0.337\text{ mA}}$$

$$I_{D1} = \frac{I_Q}{2} \Rightarrow \underline{I_{D1} = 0.168\text{ mA}}$$

$$0.168 = 0.25\left(V_{GS1} - 2\right)^2 \Rightarrow V_{GS1} = 2.82\text{ V}$$

$$V_{DS4} = -2.82 - (-10) \Rightarrow \underline{V_{DS4} = 7.18\text{ V}}$$

$$V_{D1} = 10 - (0.168)(24) = 5.97\text{ V}$$

$$V_{DS1} = 5.97 - (-2.82) \Rightarrow \underline{V_{DS1} = 8.79\text{ V}}$$

(b)

$$\text{Max } v_{CM} \Rightarrow V_{DS1} = V_{DS2} = V_{DS}(sat) = V_{GS1} - V_{TN}$$
$$2.82 - 2 = 0.82\ V$$

$$\text{Now } V_{D1} = 10 - (0.168)(24) = 5.97\ V$$

$$V_S(\max) = 5.97 - V_{DS1}(sat) = 5.97 - 0.82$$

$$V_S(\max) = 5.15\ V$$

$$v_{CM}(\max) = V_S(\max) + V_{GS1} = 5.15 + 2.82$$

$$\underline{v_{CM}(\max) = 7.97\,V}$$

$$v_{CM}(\min) = V^- + V_{DS4}(sat) + V_{GS1}$$

$$V_{DS4}(sat) = V_{GS4} - V_{TN} = 3.16 - 2 = 1.16\ V$$

$$\text{Then } v_{CM}(\min) = -10 + 1.16 + 2.82 \Rightarrow \underline{v_{CM}(\min) = -6.02\ V}$$

#2

See textbook for A_d and A_{cm} derivation.

a. For $v_1 = v_2 = 0$ and neglecting base currents

$$R_E = \frac{-0.7-(-10)}{0.15} \Rightarrow \underline{R_E = 62\ \text{k}\Omega}$$

b.

$$A_d = \frac{v_{02}}{v_d} = \frac{\beta R_C}{2(r_\pi + R_B)}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.075} = 34.7\ \text{k}\Omega$$

$$A_d = \frac{(100)(50)}{2(34.7+0.5)} \Rightarrow \underline{A_d = 71.0}$$

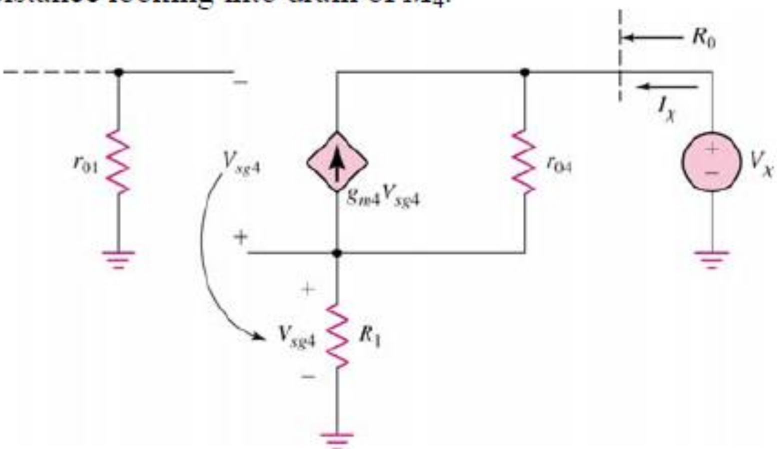
$$A_{cm} = -\frac{\beta R_C}{r_\pi + R_B}\left[\frac{1}{1+\frac{2R_E(1+\beta)}{r_\pi + R_B}}\right]$$

$$= -\frac{(100)(50)}{34.7+0.5}\left[\frac{1}{1+\frac{2(62)(101)}{34.7+0.5}}\right] \Rightarrow \underline{A_{cm} = -0.398}$$

$$CMRR_{dB} = 20\log_{10}\left|\frac{71.0}{0.398}\right| \Rightarrow \underline{CMRR_{dB} = 45.0\ \text{dB}}$$

#3

Resistance looking into drain of M_4.



$$V_{sg4} \cong I_X R_1$$

$$I_X + g_{m4}V_{sg4} = \frac{V_X - V_{sg4}}{r_{o4}}$$

$$I_X\left[1 + g_{m4}R_1 + \frac{R_1}{r_{o4}}\right] = \frac{V_X}{r_{o4}}$$

Or $R_o = r_{o4}\left[1 + g_{m4}R_1 + \frac{R_1}{r_{o4}}\right]$

$$A_d = g_{m2}\left(r_{o2} \| R_o\right)$$

$$g_{m2} = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.080)(0.1)}$$

$$= 0.179\ mA/V$$

$$r_{o2} = \frac{1}{\lambda_n I_{DQ}} = \frac{1}{(0.015)(0.1)} = 667\ k\Omega$$

$$g_{m4} = 2\sqrt{K_p I_{DQ}} = 2\sqrt{(0.080)(0.1)}$$

$$= 0.179\ mA/V$$

$$r_{o4} = \frac{1}{\lambda_p I_{DQ}} = \frac{1}{(0.02)(0.1)} = 500\ k\Omega$$

$$R_0 = 500\left[1 + (0.179)(1) + \frac{1}{500}\right] = 590.5\ \text{k}\Omega$$

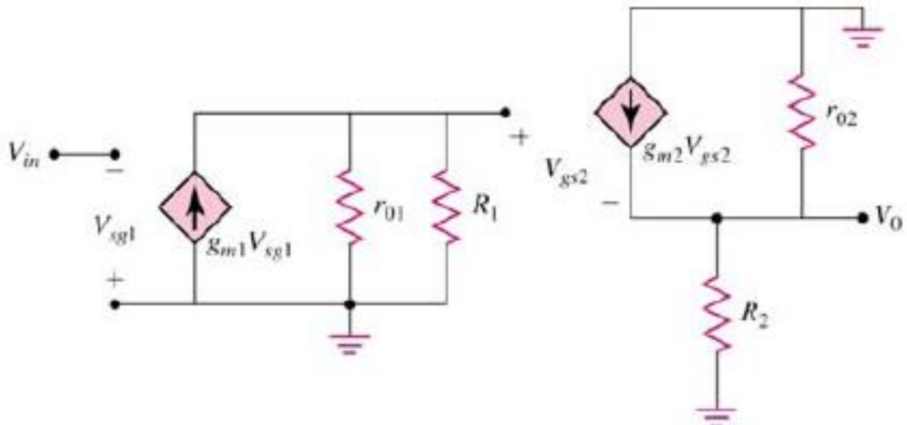
$$A_d = (0.179)\left[667 \| 590.5\right] \Rightarrow \underline{A_d = 56.06}$$

#4

$$I_2 = \frac{5}{5} = 1\ \text{mA}$$

$$V_{GS2} = \sqrt{\frac{1}{0.5}} + 0.8 = 2.21\ \text{V}$$

$$I_1 = \frac{2.21 - (-5)}{35} = 0.206\ \text{mA}$$



$$V_0 = (g_{m2}V_{gs2})(R_2 \| r_{02})$$

$$V_{gs2} = (g_{m1}V_{sg1})(r_{01} \| R_1) - V_0 \text{ and } V_{sg1} = -V_{in}$$

So $V_{gs2} = -(g_{m1}V_{in})(r_{01} \| R_1) - V_0$

Then

$$V_0 = g_{m2}(R_2 \| r_{02})\left[-(g_{m1}V_{in})(r_{01} \| R_1) - V_0\right]$$

$$A_v = \frac{V_0}{V_{in}} = \frac{-g_{m2}(R_2 \| r_{02})\, g_{m1}(r_{01} \| R_1)}{1 + g_{m2}(R_2 \| r_{02})}$$

$$g_{m2} = 2\sqrt{K_{n2}I_{D2}} = 2\sqrt{(0.5)(1)} = 1.414\ mA/V$$

$$g_{m1} = 2\sqrt{K_{p1}I_{D1}} = 2\sqrt{(0.2)(0.206)} = 0.406\ mA/V$$

$$r_{01} = \frac{1}{\lambda_1 I_{D1}} = \frac{1}{(0.01)(0.206)} = 485\ \text{k}\Omega$$

$$r_{02} = \frac{1}{\lambda_2 I_{D2}} = \frac{1}{(0.01)(1)} = 100\ \text{k}\Omega$$

$$R_2 \| r_{02} = 5 \| 100 = 4.76\ \text{k}\Omega$$

$$R_1 \| r_{01} = 35 \| 485 = 32.6\ \text{k}\Omega$$

Then $A_v = \dfrac{-(1.414)(4.76)(0.406)(32.6)}{1 + (1.414)(4.76)}$

So $\Rightarrow \underline{A_v = -11.5}$

$$R_0 = \frac{1}{g_{m2}} \| R_2 \| r_{02} = \frac{1}{1.414} \| 5 \| 100$$

$$= 0.707 \| 4.76$$

So $\underline{R_0 = 0.616\ \text{k}\Omega}$